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INDIVIDUALS OF STRATIGRAPHIC CLASSIFICATION.

INDIVIDUALS TO BE DISTINGUISHED.

SHOULD geologists map the record of physical conditions or the record of biological conditions—rocks or fossils? Both, but with distinction.

When the geologist enters the field to do stratigraphic work, one of the first problems to confront him is where he shall divide the series of rocks he is studying; and often, when reading a paper, we are perplexed to know where these lines have been drawn and what the divisions are intended to represent. This discussion is an effort to arrive at a better understanding of what we classify and what may be mapped.

Since the earliest days of geologic work there has been recognition of different kinds of rocks. For many years geologists compared the various rocks they found, and correlated them from continent to continent on the basis of like physical conditions represented in the similar lithologic characters of the rocks, Identity of physical conditions was interpreted as indicating the same date, but we now know that the physical characteristics of rocks are repeated from time to time, and are diverse in different provinces at the same time, and that therefore they do not afford criteria of contemporaneous deposition. Furthermore, conditions of sedimentation are related to currents, shores, and other moving features; the zones of deposition may migrate with these features, and an identical sediment accumulate in the migrating zone successively, not simultaneously, over adjacent areas.

After the days of William Smith a second class of divisions arose — divisions based on the fossils which the rocks contain. Fossils were found to occur in certain associations, which were called faunas, and these became the basis of a classification of rocks. On the hypothesis of special creations and destructions each fauna, wherever occurring, represented a certain date, and thus faunas became the significant figures expressing age. But special creation has given way to evolution, and we recognize migration of faunas as a fact. For instance, Walcott has stated that it took a long time for the Olenellus fauna to move round the globe. A greater or less time interval must elapse between the earliest appearance of a fauna at one place and its earliest appearance at another place remote from the first, hence, a fauna does not indicate a precise date in the narrow sense in which it was once taken. Professor H. S. Williams has pointed out that in a wider sense any fauna endures a length of time, from its initial appearance somewhere to its extinction everywhere; and this interval is an episode of evolution which has a fixed place in geologic history. In that sense faunas have definite time values, but the discovery of that value in any case is dependent on refined and extensive paleontologic research.

Accordingly, when studying a stratigraphic series, a geologist may recognize distinctions of lithologic character, variations of faunal content, and succession of physical or faunal changes. The differences enable him to define lithologic individuals, faunal individuals, and time intervals. Though often intimately related, sediments and faunas are by no means necessarily bounded by the same limits in space or in time; they constitute not identical but unlike things. They may migrate together or independently. Either may cease and the other continue. When each of them has been described and discusssed in its local and general relations, the problem of correlation in terms of earth history may be hopefully attacked; but when strata and faunas are treated under one name, confusion ensues and the conclusion becomes a guess.

It follows that we need to recognize, define, and name three separate things: (1) lithologic individuals; (2) faunal individuals; and (3) time intervals.

LITHOLOGIC INDIVIDUALS.

Definition.—Some twelve years ago there was held a conference of the geologists of the United States Geological Survey, and at that time the basis for the Geologic Atlas of the United States was laid. That foundation was planned upon the simplest lines. It was proposed that the maps should exhibit the distribution of local lithologic individuals.

Referring to the *Tenth Annual Report*, Part I, in the account of that conference we find the following statement (pp. 63–64): "Among the clastic rocks there shall be recognized two classes of divisions, viz., structural divisions and time divisions." Observe that time is set off in contrast to structure, and that structure is not defined by time. Then, defining structural units, the report says (p. 64): "The structural divisions shall be the units of cartography, and shall be designated *formations*. Their discrimination shall be based upon the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic characters change." Proceeding to emphasize that, the report further says (p. 64): "Each formation shall contain between its upper and lower limits either rock of uniform character or rock uniformly varied in character." By the latter phrase it was recognized that there might be groups of lithologic individuals which singly could not be mapped because too small—a difficulty which had to be met from the practical side. Furthermore, the report says: "As each lithologic unit is the result of conditions of deposition that were local as well as temporary, it is to be assumed that each formation is limited in horizontal extent; the formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic characters, *aided by its* *stratigraphic association and its contained fossils.*" (Italics the present writer's.)

Formations and fossils.—That the purpose of the definition is to emphasize lithologic character, and make it the essential of individuality of a formation, is clear, but the habit of classifying roughly by fossils is strong, and the few words here italicized have led many to lose sight of the distinction intended. There is a difference between using fossils as one of several means of identification and employing them as essential characters. In the former case, other characters being the same, the occurrence of a known fossil is an aid, but its non-occurrence sets no limit. In the latter case the range of the characteristic fossils defines the extent of the division. By the one method we may define a lithologic formation according to all its characters. By the second method we limit the lithologic unit by a fauna and a fauna by the lithologic unit, when either may occur beyond the other; and thus, combining two unlike things in one definition, we can recognize neither.

The writer by no means advocates disregard of fossils in the identification of formations. But abundant experience of the ablest stratigraphers shows that classification by faunas requires most refined investigation based upon thorough knowledge of the rocks. To map the formations is a necessary preliminary to determining the faunal units. We should proceed from the simple and obvious to the complex and obscure. We should trace out lithologic individuals, according to their constitution and stratigraphic associations. If these leave us in doubt, fossils may prove valuable ear-marks; but they should not set limits in the discrimination of formations. When the map of formations is made, the way is prepared for the paleontologist to ascertain the number and bounds of the faunal units and to draw the faunal map.

In mapping formations it is convenient to combine them in systems—Cambrian, Cretaceous, Eocene, etc. Fossils are the means of this preliminary rough classification, and the little evidence required is usually obtained in studying the lithology.

But it would be a slur upon paleontology to consider such arrangement final. Even were the dividing planes between great systems fixed, the precise recognition might require detailed investigation of faunas; but in many cases they are not fixed beyond question, either by faunas or by unconformities. Geology has not arrived at a final classification. We need still to accumulate physical and biological facts, to keep them distinct, and to compare them from district to district, and from country to country, before our systems can be said to be established.

The writer is indebted to his colleague, Mr. Whitman Cross, for a case in point—that of the Hermosa, Dolores, and Rico, so-called formations. Quoting from Mr. Cross's statement before the Geological Society of Washington (as revised by him), the case is as follows:

> [A diagram exhibited] represented the problems in subdivision of the great series of alternating shales, sandstones, conglomerates, limestones, and strata of intermediate lithologic character represented in the Rico quadrangle, southwestern Colorado. This series of rocks, about 4,500 feet in thickness, extends from the base of the Upper Carboniferous to the top of the Trias. The lower 2,000 feet of strata are characterized by Upper Carboniferous fossils. The intermediate three or four hundred feet by a well-defined Permo-Carboniferous fauna, and a considerable portion of the upper 2,000 feet by Triassic fossils.

Mesozoic	Dolores formation (Triassic)	Red
Paleozoic	Rico formation (Permo Carboniferous)	....
	Hermosa formation (Upper Carboniferous)	Gray

> Recognizing the importance of the time divisions indicated, the Upper Carboniferous strata have been grouped as the Hermosa formation; the strata bearing the Permo-Carboniferous fossils as the Rico formation; the strata containing Triassic fossils as the Dolores formation. With the Triassic strata are provisionally included at the present time other strata not known to be fossiliferous. The upper limit of the Dolores is a definite lithologic and structural horizon. The lower limit cannot be determined upon lithologic grounds alone. *As a line must be drawn on arbitrary grounds*, the Dolores complex has been extended below to the uppermost stratum containing

> Permo-Carboniferous fauna. This alternation of strata of different lithologic character can be subdivided in great detail when the exigencies of mapping require it. *The important lines limiting the Rico formation above and below cannot be drawn upon lithologic grounds.* If lithologic character alone is relied upon for the subdivision of this great complex embracing strata belonging partly to the Paleozoic and partly to the Mesozoic, the formation units would be of relatively minor importance, and the great historical subdivisions would not be expressed. The criterion of color applied to this complex groups the Permo-Carboniferous with the Trias. This has been done in previous general discussions of this complex in this region. In fact, the Permo-Carboniferous beds should be grouped with the Carboniferous if the larger elements of time division are to receive recognition upon the geologic map of the Rico quadrangle. (Italics the present writer's.)

There are two questions involved: First, what Mr. Cross's map expresses; second, what it should express. The Hermosa, Rico, and Dolores are clearly not formations in the sense defined in the *Tenth Annual Report*, for lithologic continuity is divided at the top and bottom of the Rico on the basis of contained fossils. They are intended to be faunal divisions, but their limits are very ill defined, since fossils are commonly so few in the Red Beds that the finding of them higher or lower in the series is a matter of accidental discovery rather than of occurrence. The map appears, then, to express indefinitely the arbitrary application of a time scale (Paleozoic, Mesozoic or Carboniferous, Permo-Carboniferous, Triassic) to a series which is capable of division into lithologic individuals. Were it so divided it would yield a record of physical conditions, a record which is now obscured by this classification.

It is an important fact that conditions of erosion and deposition were continuously favorable to the accumulation of red sediments while biologic migration or evolution modified the organisms present from Paleozoic to Mesozoic types. But in discussing the formations their continuity is the essential, just as in describing the faunas their discontinuity would be. To impose the division of the latter upon the lithologic individual is misleading, and to call the faunal units "formations" in a publication for which that term has been accurately defined is a misuse of the word.

A very similar case is that of the Shenandoah limestone, which carries Cambrian fossils in its lower portion and Calciferous fossils near the top. But, though it thus corresponds to parts of two great periods, as we usually classify geologic time, it is mapped as one formation because it is a lithologic unit.

Formation names. — "The formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic characters, aided by its stratigraphic association and contained fossils." Following this rule (*Tenth Annual Report*, Part I, p. 64), various cases may arise, some of which are illustrated in the accompanying diagrams.

Figure 1 shows the *m* shale passing into a limestone which retains identical stratigraphic associations. Being exactly continuous stratigraphic units, they should retain the same geographic name on grounds of convenience and simplicity.

Figure 2 shows the *m* shale grading into a limestone with prolonged overlap, so that the two rocks must be discriminated in one area. Not only are they lithologically different but they have different stratigraphic associations, and they should receive distinct geographic names: *m* shale and *n* limestone.

Figure 3 shows the *m* shale continuing as an individual with reduced thickness into new stratigraphic associations. Individuality is not dependent on thickness nor on stratigraphic association only; it is determined by continuity, and the formation may retain its name, *m* shale. But the group *pms* cannot then be called the *m* group, because *m* would have two meanings, one for a simple part, and one for a complex whole.

Figure 4 shows the *m* shale replaced by five formations, two of which, *B* and *D*, are shales like it. Individuality is here lost in multiplicity. Neither *B* nor *D* can be distinguished as representing *m*, which must, accordinly, give way where they divide into two. The complex *ABCDE* may be called the *m* group, since it has equivalent stratigraphic associations with *m*.

Figures 5 and 6 illustrate the occurrence and naming of local lenses in a formation where such divisions are not of sufficient extent to justify a distinct series of names for the lens and the parts of the formation above and below it. One lens may receive the formation name, but two or more must be named distinctly.

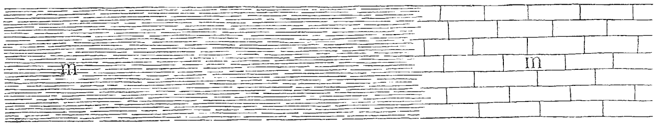
Figure 7 presents the case of a formation which is a least practicable lithologic individual for mapping, but which includes fractional parts that are important in discussion. The fractional character of the parts may be indicated by calling them members, each member being given a distinctive geographic name.

Lithologic individual and thickness.—Thickness is not an essential character of a lithologic individual. Layers, strata, beds, and their complexes vary so generally in this respect that individuality based upon constancy thereof must be lost in a short distance. And if thickness be not constant for any one individual, still less can volume be considered an element of the definition of formations in general. Lithologic individuality knows no such limits. Continuity of rock character is the essential core of the definition, and this may extend through a hundred or a thousand feet or more or less.

The writer has avoided the use of the phrase "lithologic unit," because discussion developed the fact that, in the minds of some, unit means a definite quantity, and these persons think that a thick formation should be a group or series, because of its magnitude. Not volume, but uniformity of constitution, defines a lithologic individual or " formation."

Lithologic individual and time.—Thickness of strata, at right angles to bedding, is considered a measure of the epoch of deposition, due account being taken of the estimated rate. Thus for that particular place the lithologic unit is significant of definite lapse of time. It bears, however, no mark of date. If we trace the formation a hundred or a thousand miles, and again measure its thickness, another determination of an epoch is obtained, again without date. Are the epochs identical ? The common assumption is that they are, and one reads of the epoch of the Dakota formation without reference to locality. Thus used, the phrase should mean all the time during which the Dakota sandstone was spread from its eastern to its western

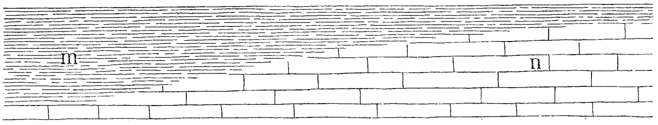
I



m *shale or formation*

m *limestone or formation*

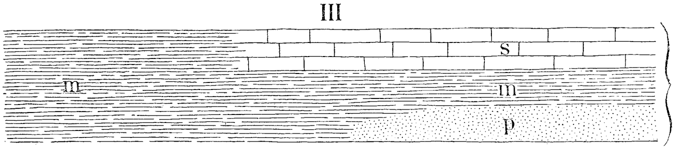
II



m *shale or formation*

n *limestone or formation*

III

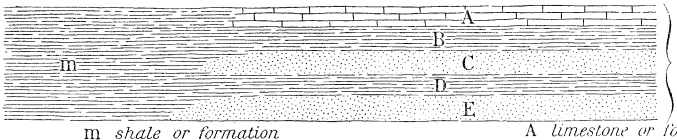


x group

m *shale or formation*

s *limestone or formation*
m *shale or formation*
p *sandstone or formation*

IV

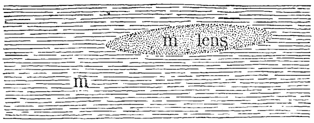


m *group*

m *shale or formation*

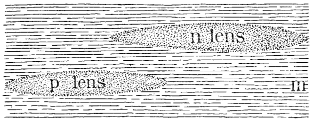
A *limestone or formation*
B *shale or formation*
C *sandstone or formation*
D *shale or formation*
E *sandstone or formation*

V



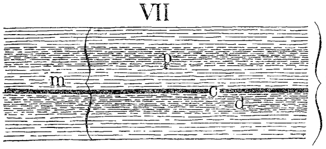
m *shale or formation*
and m *lense*

VI



m *shale with* n *and* p
sandstone lenses

VII



m *shale or formation including* p *fire clay member,* c *coal member, and* d *fire clay member* limit. Since that transgression took a long time, the eastern Dakota sandstone is older than the western; and as the advancing zone of sand accumulation, following the shore, was in turn followed by a zone of shale deposit, the eastern sands were being buried under Benton shale while the western sands gathered. When the transgression ceased and Niobrara chalk was laid down, the conditions were more nearly uniform throughout the sea. Niobrara then probably marks approximately one and the same epoch throughout its extent. Benton may do so in less exact degree; and Dakota corresponds at an eastern point to the beginning, at a western to the closing, of the cycle of deposits.

It is convenient to conceive the time scale as marked by horizontal lines. On such a scale the Dakota formation would be represented by a diagonal line, and the Niobrara by a nearly horizontal line.

The writer does not put these ideas forward as new; but in defining a formation it is important to clear away certain misleading conceptions that appear in the literature and in discussion of the points at issue. Only at a particular place does a formation belong to a definite age: when traced to another locality it may be older or younger.

FAUNAL UNITS.

Classification by faunas.— The term faunal unit or individual is here used as a parallel to lithologic individual, to designate a set of strata characterized by a common fauna. The writer does not undertake to say whether a fauna should be defined by varieties, species, or genera; by recognition of one or many associated organisms. It may be granted that a fauna is something which each working paleontologist will define for himself within certain broad limits, just as lithologic character is something which each stratigrapher defines for himself within certain limits. But classification of strata by faunas is a different thing from classification by formations.

Professor Williams, in 1897, published a paper on dual nomenclature, in which he clearly stated the distinction which the present writer would now emphasize between a lithologic individual and a faunal unit.

Following the language in which a formation is defined in the *Tenth Annual Report*, a faunal unit may be defined as follows:

LITHOLOGIC INDIVIDUAL.	FAUNAL UNIT.
"The structural divisions shall be units of cartography, and shall be designated *formations*. Their discrimination shall be based upon the local sequence of rocks, lines of separation being drawn at those points in the stratigraphic column where lithologic characters change."	The faunal units shall be units of correlation, and shall be designated stages.[1] Their discrimination shall be based upon their fossil content, lines of separation being determined at those points in the stratigraphic column where faunas change.

Pursuing the description of a faunal unit, or stage, we may say further: As a faunal unit is characterized by the life which it contains, and as organisms are migratory, it is not to be assumed that a stage is limited horizontally. It may be recognized in diverse provinces or continents, and therefore the name which a faunal unit receives should not be a local name, but should be applied wherever that unit is recognized.

Distinctions between formation and stage.— A formation is a set of strata characterized by and limited to uniform constitution. A stage is a set of strata containing and limited to a certain fauna.

Lithologic constitution results from conditions which are local and temporary, and which, though migratory, are rarely more than provincial in extent. A fauna, though evolved in adaptation to local conditions, may be capable of world-wide migration. A formation, therefore, is geographically limited; a fauna is not, necessarily.

Physical conditions which determine rock constitution are recurrent and repeat the deposition of similar sediments. But organisms, once extinct, do not reappear. Accordingly, a

[1] The term *stage* is here used provisionally, to afford a word for the purposes of this discussion only.

formation may belong to any geologic age; a fauna belongs only to that age in which it was evolved and died out.

A principal object in studying formations is to read the physical history of the earth, but the principal object of investigating fossils is to get at the life history. Each is an essential aid to the other, and the time relations of fossils are fundamental. But the two lines of inquiry should not be confused. They are confused when we call a stage a formation, or *vice versa*, or place the limitations of the one upon the other.

STEPS IN GEOLOGIC SCIENCE.

The question with which this article opens may now be given a fuller answer. The first step in the geologic study of any locality is to ascertain the relations of the rock masses, and those relations are most happily expressed in a map which exhibits the distribution of formations. This map illustrates local facts. It can be complete in itself, even though no connection is established between the facts of that particular district and those of the world at large, but if it be a correct map it will fit into the general record when the connections are traced.

The second step in geologic investigation is the detailed study of faunas and their distribution in stages. To this second step the first is an essential, as a good topographic map is to both. Through close analysis of the faunas and comparative study of their distribution, the data may be gathered for a map of the stages represented in the district. This map of stages may in some cases resemble closely that of the formations, but in others there will be marked differences.

With the development of maps showing the distribution of stages we may arrive at correlation of events, and thus be able to compare physical conditions the world over, fitting into its place with some degree of exactness the record of the formations for any locality. Thus correlation is the third step, a step which may be facilitated through other lines of research, but which is fundamental in broad studies of the earth's history.

With a better knowledge of the physical geography of the globe at successive epochs we may more hopefully attack the great problems of mountain growth, continental development, and earth dynamics. But our first work is to map the lithologic individuals, while our associates, the paleontologists, distinguish the faunal units of stratigraphy.

BAILEY WILLIS.